Experimental study of blood laminar flow through a stented artery

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Abstract- **The objective of this research is to study the blood flow close to the wall of a stented artery. Indeed, previous works have showed that the restenosis phenomenon is induced by the endothelial cells stimulation due to the wall shear stress values. The coronary angioplasty is responsible of wall shear stress modification, mainly between the stent struts, at the inlet and the outlet of the endoprothesis. That is why, to study the flow disturbances through a stented section, we built an in vitro model reproducing the struts shapes of a marketed endoprothesis. The experimental artery is composed of a see-through square section vein, which reproduce the struts design with a magnitude of 100. A programmable pump provide a steady or a pulsatile flow. By using the velocimetry per imagery of particle (PIV) optical method we have explored the flow between and over the stent branches, in order to assess and to quantify the wall shear stress and to locate the interesting zones.**

Keywords- **Stent, endoprothesis, coronary artery, restenose, wall shear stress, endothelium cell.**

I.INTRODUCTION

For several years the leading cause of morbidity and mortality in the developed countries has been the whole of the disorders of the cardiovascular system and mainly the phenomenon of stenosis in coronary arteries. Since the 80's, there is an alternative to the usual balloon angioplasty. Indeed, the use of tiny metallic scaffolds (named coronary endoprothesis or stent) has surpassed all expectations. Now, the use of the technique of stent is generalized in practical clinic (representing 60-90 percent of procedures), approximately 1,000,000 patients worldwide undergo a non surgical coronary artery interventional procedure yearly. A coronary stent is a small, slotted, stainless steel or nickel tube mounted on a balloon catheter, which remains in the artery. The procedure is the following one: the coronary stent is placed over the angioplasty balloon and moved to the site of lesion. The stent expands with the balloon and remains in place after the balloon is deflated and removed, thereby serving as a mechanical scaffold to prevent restenosis.

Unfortunately, there is still a very important disadvantage. Indeed the rate of restenosis, response to stent implantation, still occurs frequently (in 20% or 40% of cases). In-stent restenosis occurs mainly at the area of the injury vascular induced by the implantation of the endoprothesis but not exclusively. It also frequently appears in all the zones where the flow can be disturbed , in particular between the branches of stent. The composition of in-stent restenosis includes vascular smooth muscle cell and endothelium cell i.e. it consists predominantly of neointimal growth. Previous study showed that the areas of endothelium exposed to a low and oscillating stress correspond to the places where the restenosis develops preferentially [1], indeed, endothelium cells are an interface extremely active, able to bring an answer differentiated according to the stresses physics of its environment [2]. The morphology and the functions of the endothelium cells are connected to the local value of the shear stress induced by the flow. Arguments in favor of shear stress is that it is known to be involved in a variety of processes related to cellular growth probably through the activation of several genes [3]. The flow behaviour in the vicinity and between the branches of stent after its implantation, generates a local modification of local shear stress, and thus will induce an evolution of endothelium, with consequence, in the long term, the phenomenon of restenosis.

Within the framework of our study, we thus devoted to identify, and to characterize, the different flow behaviour zones induced by a customed model of stent by using velocimetry per tracking particles (PTV) and the velocimetry per imagery of particles (PIV) optical method.

II. METHODOLOGY

Several types of endoprothesis are available exhibiting a wide difference in their mechanical properties according to the design, material and technology used. This work focuses on one model of stent (Helistent®, Hexacath Production), this model is one frequently use in non surgical intervention in France (in particular in C.H.U of Poitiers). It is a model characterized by sinusoidal rings connected by a helicoid of bonds in " H " (Fig. 1), it's length being of 10 mm and its diameter of 4 mm.

Fig. 1: Stent characterized by sinusoidal rings connected by a helicoid of bonds in " H "

In order to access to unknown data (gradient of velocity, wall shear stress), a specific bench has been developed which provides a Poiseuille flow, in steady flow, through a rectangular channel. One of the flat inner face reproduces the struts geometry and shape of the stent (Fig.2). A geometric scale factor of 100 was applied to get the more

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accurate and fine velocity mapping, that way the roughness of the flat inner have a thickness of 1 cm. In order to investigate optically the flow behaviour, all channels faces are made of plexiglas.

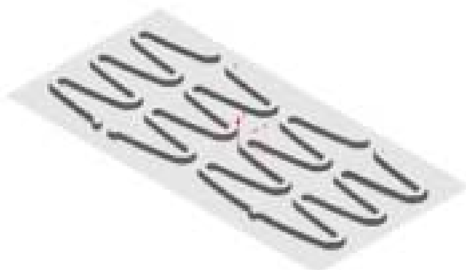

Fig.2: Face simulating the implantation of stent

The choice of material was guided by the technique of visualization used. Indeed, the method employed was P.I.V. Particle imaging techniques depend on the interaction between radiation and seed particles to record the location of each particles. In order to allow the visualization of the flow using this technique, we have to carry out a transparent and plane model of geometry of stent (Fig 2.) (this to avoid the phenomenon of scattering and diffractions). To define the geometry of this " flat " stent and the scale factor, we had to carry out different similarities according to the type of flow (stationary or pulsatile flow). For the stationary flow, we used a similarity of Reynolds (1), (based on the hydraulic diameter) and a similarity for τ_p (2), (τ_p is the wall stress factor). In the case of pulsatile flow, another similarity factor was calculated (number of Witzig-Wommersley (3) [4]).

(1) $$\frac{2.q_{v1}}{\mu_1 r_0} = 3\frac{q_{v2}}{\mu_2(x_0+2y_0)}$$ Similarity of Reynolds

(2) $$\frac{3\mu_2.q_{v2}}{2.x_0 y_0^2} = k'.\frac{4\mu_1 q_{v1}}{\pi r_1^3}$$ Similarity for τ_p

(3) $$\frac{\rho_1 w_1 r_0}{\mu_1} = \frac{\rho_2 w_2 x_0 y_0}{\mu_2\left(x_0+y_0\right)}$$ Witzig-Wommersley

where:

μ_1 viscosity of blood in the artery
μ_2 viscosity of blood in the model
qv_1 flow of blood in the artery
qv_2 flow of blood in the model
r_0 diameter of artery
x_0,y_0 width and height of the rectangular section
k' factor of correction
w_1 pressure beat in the artery
w_2 pressure beat in the model

The blood like viscosity fluid used was a water glycerin mix. The feeding circuit is closed, the flow is ensured by a programmable hydraulic generator (FABRE GH1155). The components used to apply P.I.V was a Laser (Spectra physics), a CCD video camera, and a data-processing central processing unit. Horizontal and vertical visualization planes of, i.e. over and between the stent branches have been investigated. The steady flow and a physiological blood flow have been performed.

III. RESULTS

Visualization via the horizontal and vertical planes gives access to all the required data. The PTV allows to reach to the streamlines and the velocity fields knowing the obtrusion lap time (Fig 3).Particularly, we may observe the over flow discharge between the struts and its impact on the wall. From the velocity fields, we have computed the wall shear stress distribution and its gradient (Fig 3.). Until now, only the steady flow was studied, the first results show that there are indeed distinct zones within the struts area. Our experimental results agree with those of previous studies (generally numerical study [5]). The results indicate that the change in face structures creates large changes in the shear stress field compared to models where the face was held constant [6]. The difference of shear stress field is particularly obvious between the input area of stent and the stagnation zones related to the stent geometry studied.

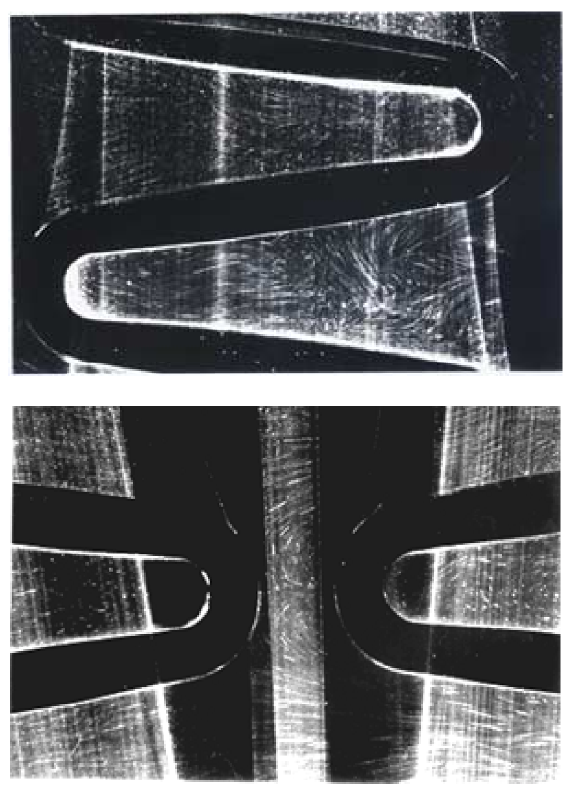

Fig. 3 : Streamlines visualization by PTV for two different grid shapes.

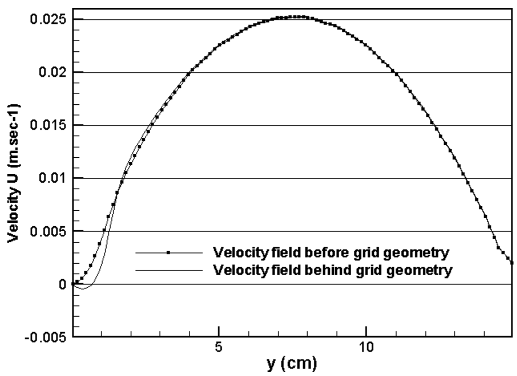

Fig.4: Velocity profiles behind a stent strut model

IV. CONCLUSION

With this experimental study, we have identified accurately the risk zones, which constitutes a innovating study. We must now undertake a numerical study (mixed method STARCD©) in order to corroborate our first results. Currently, we only finished the 3d mesh of stent using this software (Fig. 5), and the resolution is still running. This studies show how stent design can be modified to minimize the risk of flow-related restenosis. Exploration of mechanotransduction induced phenomenon by stent implantation may allow a rational approach for new stent design, reducing the need for drug treatment.

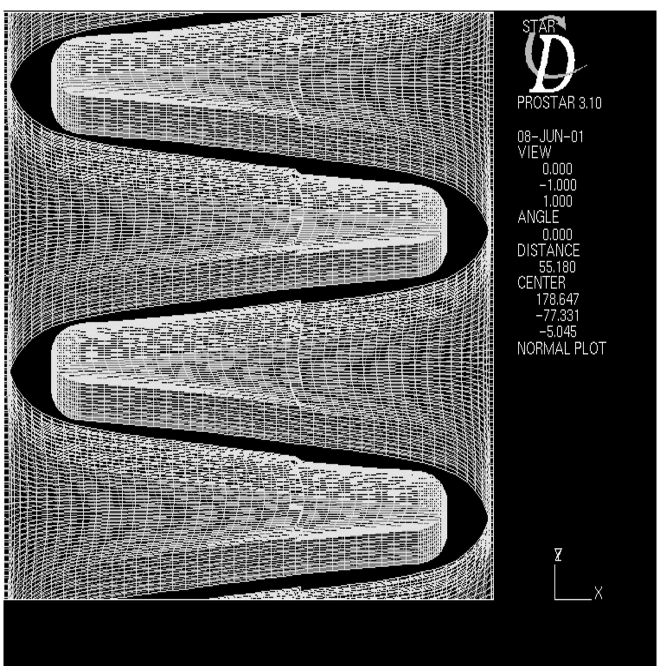

Fig. 5: 3d mesh of stent strut with the software Star-CD©

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